EUROPEAN SOUTHERN OBSERVATORY

VLT REPORT No. 63

FIELD AND PUPIL ROTATIONS FOR THE VLT 8 M UNIT TELESCOPES

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VLT

Very Large Telescope Project

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Contents

1 Definitions and conventions

The following definitions are assumed:

- a = altitude (measured zenithwards from the horizon)
- A = azimuth (measured westwards from the southpoint)
- h = hour angle
- ϕ = Paranal latitude = – 24° 37'
- δ = declination
- $\omega_o = \dot{h} = 15°/hr$ = sideral rate
- p = parallactic angle
- Figure 1 shows the coordinate system convention for an altitude-azimuth telescope mounting in the south hemisphere.
- F_{Ca}, F_N and F_C = Field rotation at the Cassegrain, Nasmyth and Coudé (Combined) foci respectively.
- P_N and P_C = Pupil Rotation at the Nasmyth and Coudé (Combined) foci respectively.
- D_{Ca}, D_N and D_C = Pupil Rotation with respect to the Adapter at the Cassegrain, Nasmyth and Coudé (Combined) foci respectively.
- Like the NTT, when the Telescope Tube is pointing close to the horizon and one stands up behind the mirror cell, the Platform A (Nasmyth focus A) is to the left side and the Platform B (Nasmyth focus B) to the right.
- **Sign convention:** angles are positives in the standard counterclockwise direction and the observer is in front of the incoming beam. The convention for the zero angle for both the field and pupil is represented in the Figure 2, where A = 0° and a = 90°.

2 Field Rotation

2.1 At the Cassegrain and Nasmyth Foci

The field rotation at the Cassegrain focus and on the Nasmyth platform as a function of the hour angle and the declination is given by:

$$
\begin{aligned}
F_{Ca} &= -p \\
\dot{F}_{Ca} &= -\dot{p} \\
\ddot{F}_{Ca} &= -\ddot{p} \\
F_N &= p \pm a \\
\dot{F}_N &= \dot{p} \pm \dot{a} \\
\ddot{F}_N &= \ddot{p} \pm \ddot{a}
\end{aligned}
$$

where the sign + corresponds to the Nasmyth B Platform and

$$
\begin{aligned}
\tan p &= \frac{\sin h}{\tan\phi\cos\delta - \sin\delta\cos h} \\
\frac{\dot{p}}{\omega_o} &= \frac{\cos\phi\cos A}{\cos a} \\
\frac{\ddot{p}}{\omega_o^2} &= -\frac{\sin A\sin 2\phi}{2\cos a} - \frac{\sin a\sin 2A\cos^2\phi}{\cos^2 a} \\
\sin a &= \sin\delta\sin\phi + \cos\delta\cos h\cos\phi \\
\frac{\dot{a}}{\omega_o} &= -\sin A\cos\phi \\
\frac{\ddot{a}}{\omega_o^2} &= -\frac{\dot{A}}{\omega_o}\cos A\cos\phi \\
\tan A &= \frac{\sin h}{\cos h\sin\phi - \tan\delta\cos\phi} \\
\frac{\dot{A}}{\omega_o} &= \sin\phi + \tan a\cos A\cos\phi
\end{aligned}
$$

These equations are valid for a telescope situated in the South Hemisphere according to the coordinates fixed in the Figure 1. Note that A is measured clockwise direction.

There is also a sign change with respect to the equations for the North hemisphere in the terms containing the azimuth coordinates. At North laltitudes, the azimuth angle is defined with respect to the North direction.

According to the mechanical limitations of the movement of the telescope tube, the computed values for the altitude angle (a) were always smaller than

90°. Also the inverse trigonometric functions (p and A) were computed taking into consideration the sign of quotients in order to find the right quadrant. In some cases, the angles in the second and third quadrants were defined with negative values in order to be coherent with the field or pupil orientations illustrated on Figure 2.

A plot of such rotations are given in Figures 3 and 4. All the results were obtained for Paranal latitude (where the VLT will be built). The blind point at the zenith was specified to be less than one degree. The curves with declinations $\delta = -24° \ 7'$ and -25° 7' show the two closest values.

The sideral rate and its square are given by

$$\begin{aligned} \omega_o &= 15 \, arcsec/s \\ \omega_o^2 &= 1.091 \times 10^{-3} \, arcsec/s^2 \end{aligned}$$

The zero rotation reference point for the field and pupil is *fully arbritrary*; the zero can be defined everywhere, only the set of curves have to be shifted up or down accordingly. The curves plotted here are defined in agreement to the references shown in the Figure 2. The sky and pupil orientations are represented by the marks in the upper cases. The pupil is defined directly by the M2 mirror.

When the telescope is pointing to the zenith ($a = 90°$) and $A = 0°$, an observer (looking at the Cassegrain focus with his head pointing to the North) will perceive the field and pupil orientations as showed in the figure. The sky south direction as appears on the focal plane is directed to the upper point. This position defines then the zero degrees. Finally the arrow on the circle shows the rotation positive direction.

At the Nasmyth platform B, the same observer will note that the sky's south direction points to his left. In this case and by convention, the field is already rotated of 90° respect to the upper point. The pupil is also rotated and inverted as is represented in the same figure.

Table 1 shows the maximal velocities and accelerations of the field and pupil at the different foci.

2.2 At the Coudé and Combined Foci

Figure 5 shows the Coudé Beam set up. The mirror train from M4 to M8 does not modify the Nasmyth field rotation provided that all the mirrors lie on the same plane. Indeed, this plane moves together with the telescope structure. The lateral magnification between the Nasmyth focus (after M4) and the Coudé is +3.33. Therefore the rotation and orientation of the field at the Coudé focus *in the telescope structure frame* is the same as for the folded Nasmyth one. On the

Table 1: Maximal velocities and accelerations

		FIELD		
		Cassegrain	*Nasmyth*	*Coudé*
Velocity	δ_N	26.03 '/s HA = 0	-26.03 '/s HA = 0	-23.21 "/s HA = -6 hr
	δ_S	-26.08 '/s HA = 0	26.08 '/s HA = 0	-23.27 "/s HA = -6 hr
Acceleration	δ_N	7.70 "$/s^2$ HA = -0.02 hr	-7.77 "$/s^2$ HA = -0.02 hr	0.104 "$/s^2$ HA = 0
	δ_S	7.65 "$/s^2$ HA = 0.02 hr	-7.72 "$/s^2$ HA = 0.02 hr	0.103 "$/s^2$ HA = 0
		PUPIL		
Velocity	δ_N	-	13.64 "/s HA = -1.2 hr	-26.15 '/s HA = $-1.3\times^{-4}$ hr
	δ_S	-	13.58 "/s HA = -1.2 hr	25.98 '/s HA = $2\times^{-4}$ hr
Acceleration	δ_N	-	-0.104 "$/s^2$ HA = 0	7.77 "$/s^2$ HA = 0.02 hr
	δ_S	-	-0.103 "$/s^2$ HA = 0	7.72 "$/s^2$ HA = -0.02 hr
$\delta_N = -24°7'$ $\delta_S = -25°7'$ HA = Hour Angle in hours				

Earth frame (looking the image coming from M8 as is represented in the lower case of the Figure 2), the rotation of the field is consequently given by:

$$\begin{aligned}
F_C &= -F_N + A + 90^\circ = -p \mp a + A + 90^\circ \\
\dot{F}_C &= -\dot{p} \mp \dot{a} + \dot{A} \\
\ddot{F}_C &= -\ddot{p} \mp \ddot{a} + \ddot{A} \\
\frac{\ddot{A}}{\omega_o^2} &= -\sin 2A \cos^2\phi(\tan^2 a + \frac{1}{2}) - \frac{1}{2}\tan a \sin A \sin 2\phi
\end{aligned}$$

The sign – corresponds to the rotation generated by the coudé train issued from the B Nasmyth focus.

Figure 6 gives some curves for different declinations. The two coudé images generated by the two coudé trains will out of phase of $2a$.

At the Incoherent Combined Focus the field rotation velocity is the same as for the Coudé Focus. Indeed, all the mirrors composing the combined train are fixed on the Earth frame. However, the field orientation may be different from one telescope to the other depending of the optical combined configuration.

3 Field Orientation at the Incoherent Combined Focus

The main restrictions concerning the superposition of the fields generated by the four telescopes are the field orientation and the scale factor which have to be the same for the all beams. Therefore, in any Telescope array (linear or trapezoidal), the mirror train of each telescope must obey a number of logical limitations:

1. All the Nasmyth foci must be the same.
2. The magnification factor of all mirror trains must be the same.
3. The design configuration of each train has to be the same for all Telescopes.
4. The mirror M9 that deflects the coudé beam towards the combiner train and the last mirror that send the exit beam to the combiner mirror must have the same orientation. In other words, the normals to these two mirrors have to be nearly parallel and lie in a vertical plane passing by the centers of the mirrors. This restriction is illustrated in Figure 7 (the mirror configuration at the combined room is not fully defined yet).

Figure 8 shows the field orientation for an individual combined train. The orientation at both the coudé and the combined foci are represented by the cross-arrow. In order to keep the same field orientation for any telescope configuration, the final image must stay fixed when the complete telescope moves along a circle centered at the combined focus.

4 Pupil rotation

4.1 At the Cassegrain and Nasmyth Foci

The secondary mirror (M2) defines the entrance pupil; the zero reference is defined as shown in Figure 2, in this case, the telescope points to the zenith, the azimuth angle is zero and the observer is looking the incoming light. In the Cassegrain focus frame, the pupil of course does not rotate. However if an instrument is mounted on the Cassegrain adapter and this one is locked to the field rotation, then the instrument will see the pupil rotate according to:

$$D_{Ca} = p$$

On the Nasmyth platform frame, the pupil rotates following the altitude angle:

$$P_N = \pm a$$

where the sign + corresponds to the B adapter. Now, the field rotates following the equation F_N, therefore the rotation of the pupil with respect to the adapter is given by:

$$D_N = -p$$

It is the same relative rotation as for the Cassegrain adapter but in opposite direction (Figure 3).

4.2 At the Coudé and Combined Foci

The pupil image at the folded Nasmyth focus (below M4) has the same orientation as M2. Since the coudé train is a positive magnification projector, the pupil image orientation at M8 remains the same. At this location, the pupil rotates with respect to the Earth frame as

$$P_C = \mp a + A + 90^\circ$$

Once again, the constant term is arbitrary and here is used to match the reference zero point given in Figure 2. The sign - corresponds to the direction generated by the B coudé train.

Finally, the differential rotation between the pupil and the image (coudè adapter frame) is given again by:

$$D_C = p$$

In other words, because the azimuth angle is added to both the image and pupil, the differential rotation between them remains the same.

Table 2: Field and Pupil rotations for the VLT

Focus	Field Rotation	Pupil Rotation	P-F Rotation
Cassegrain	$-p$	0	p
Nasmyth	$p \pm a$	$\pm a$	$-p$
Coudé	$-p \mp a + A + 90°$	$\mp a + A + 90°$	p
Combined	$\lvert -p \mp a + A + 90° \rvert$	$\lvert \mp a + A + 90° \rvert$	$\lvert p \rvert$

Figures 9 and 10 show the pupil rotations at the Nasmyth B platform and at the Coudé or Combined focus respectively.

Table 2 shows a summary of the different rotations.

References

1. K. Wirenstrand. ESO Technical Note, February 9, 1984.

2. J. Nelson. Geometrical Relations for an Altitude-Azimuth Telescope. UC TMT Report No. 49. December 1981.

3. The Astronomical Almanac.

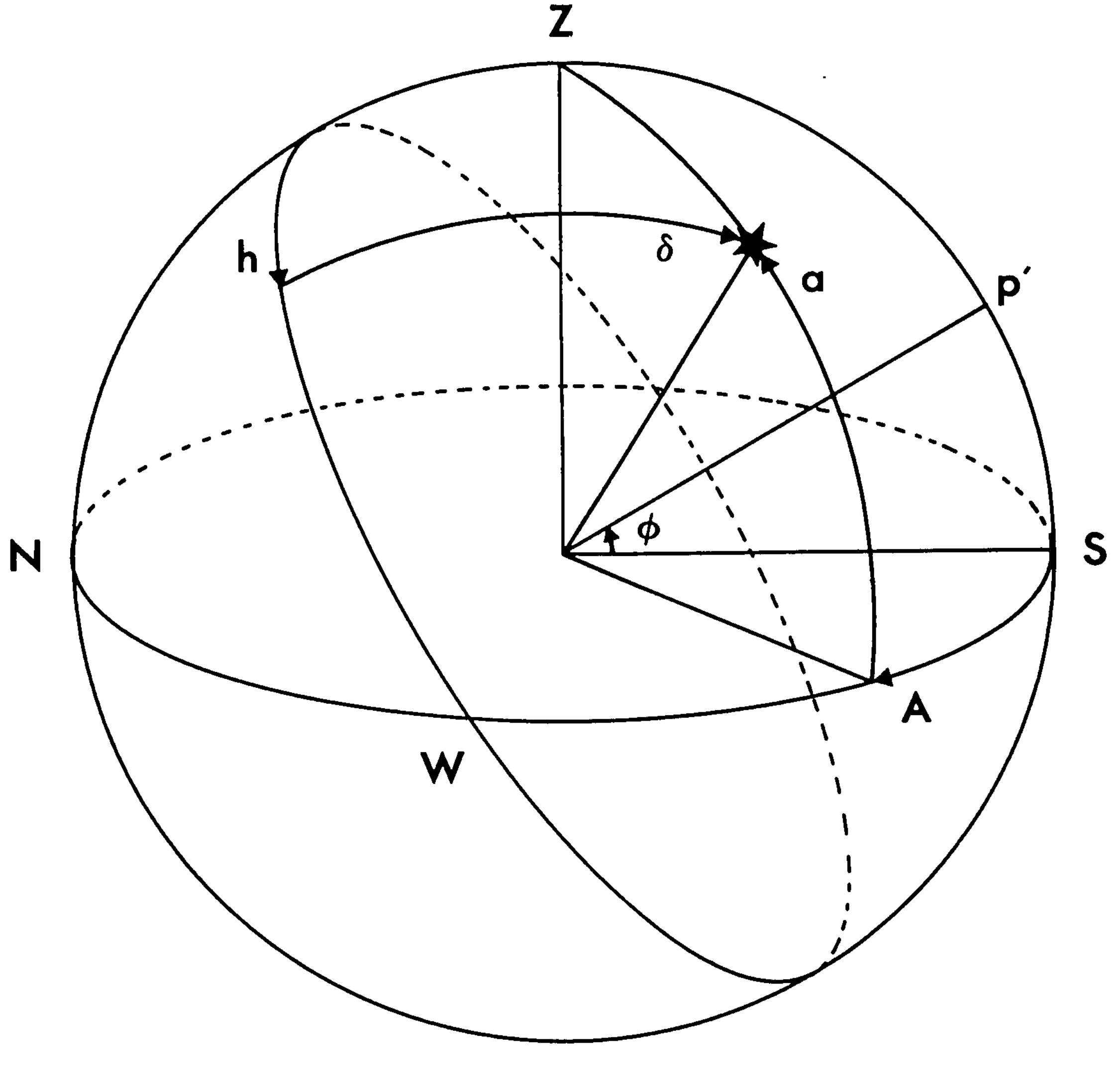


Figure 1. Coordinate system convention for an altitude-azimuth mounting at the South Hemisphere. δ and ϕ are negatives in this schema.

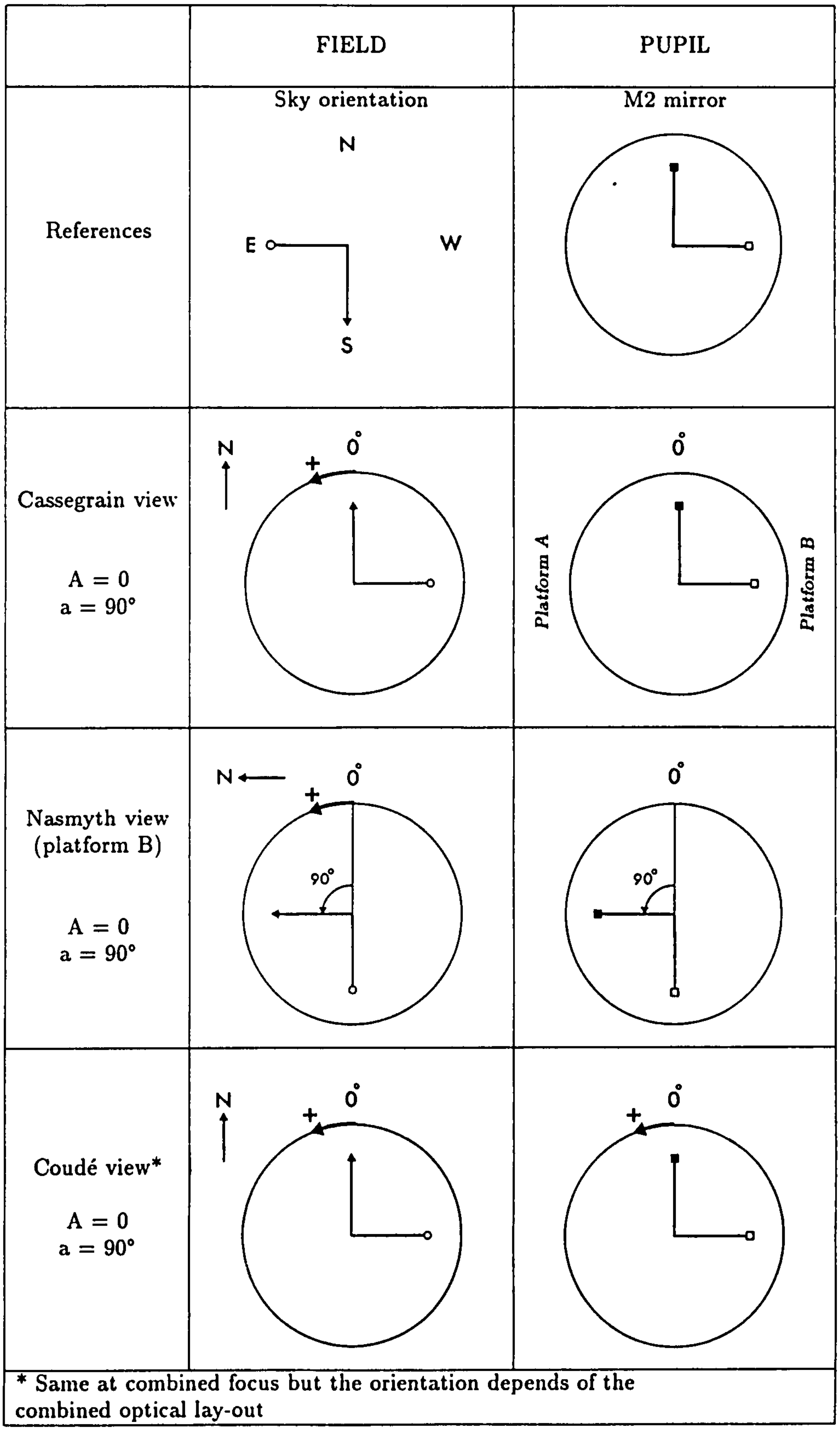
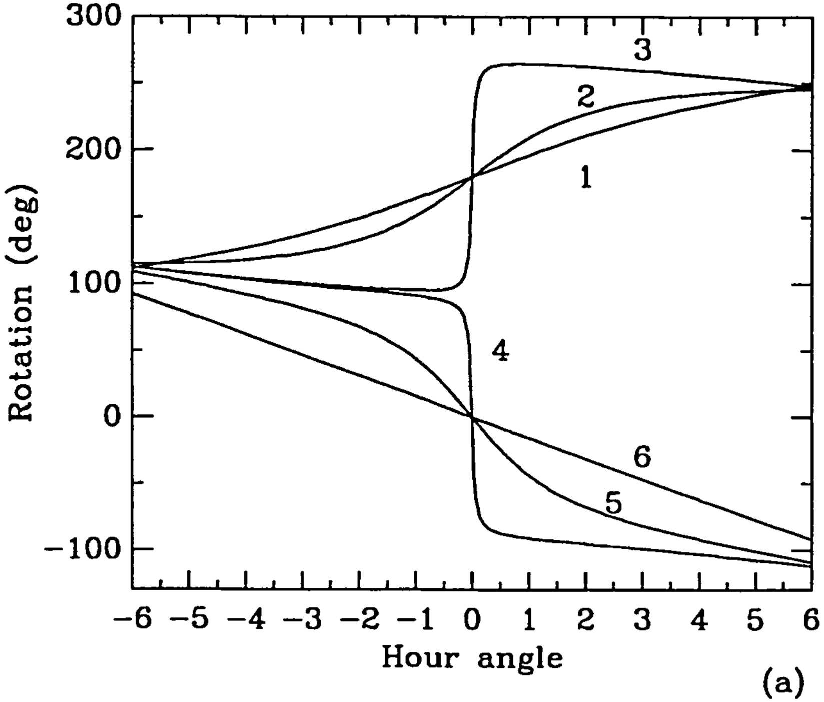
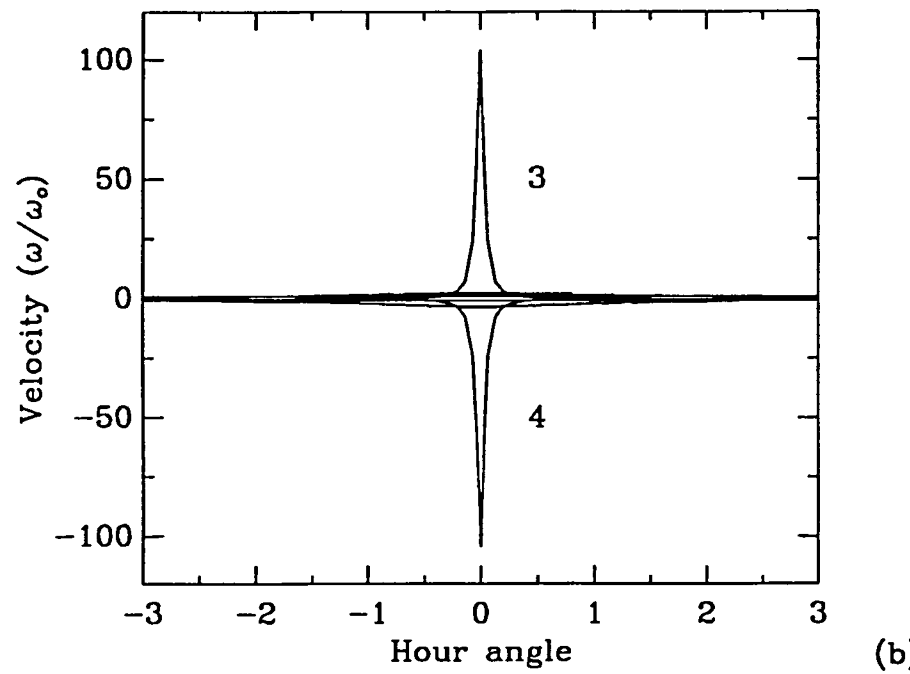
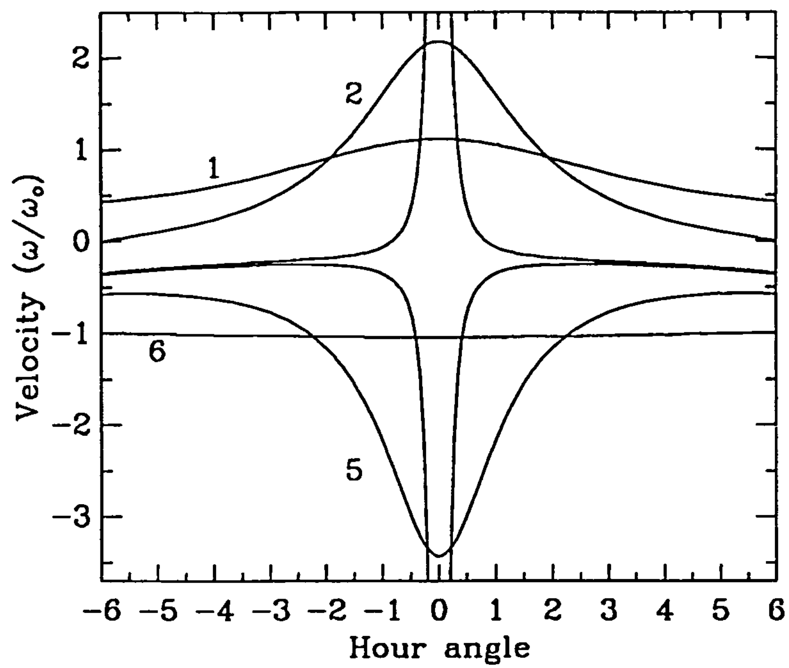


Figure 2. Zero reference point for the field and pupil rotations at the different foci.







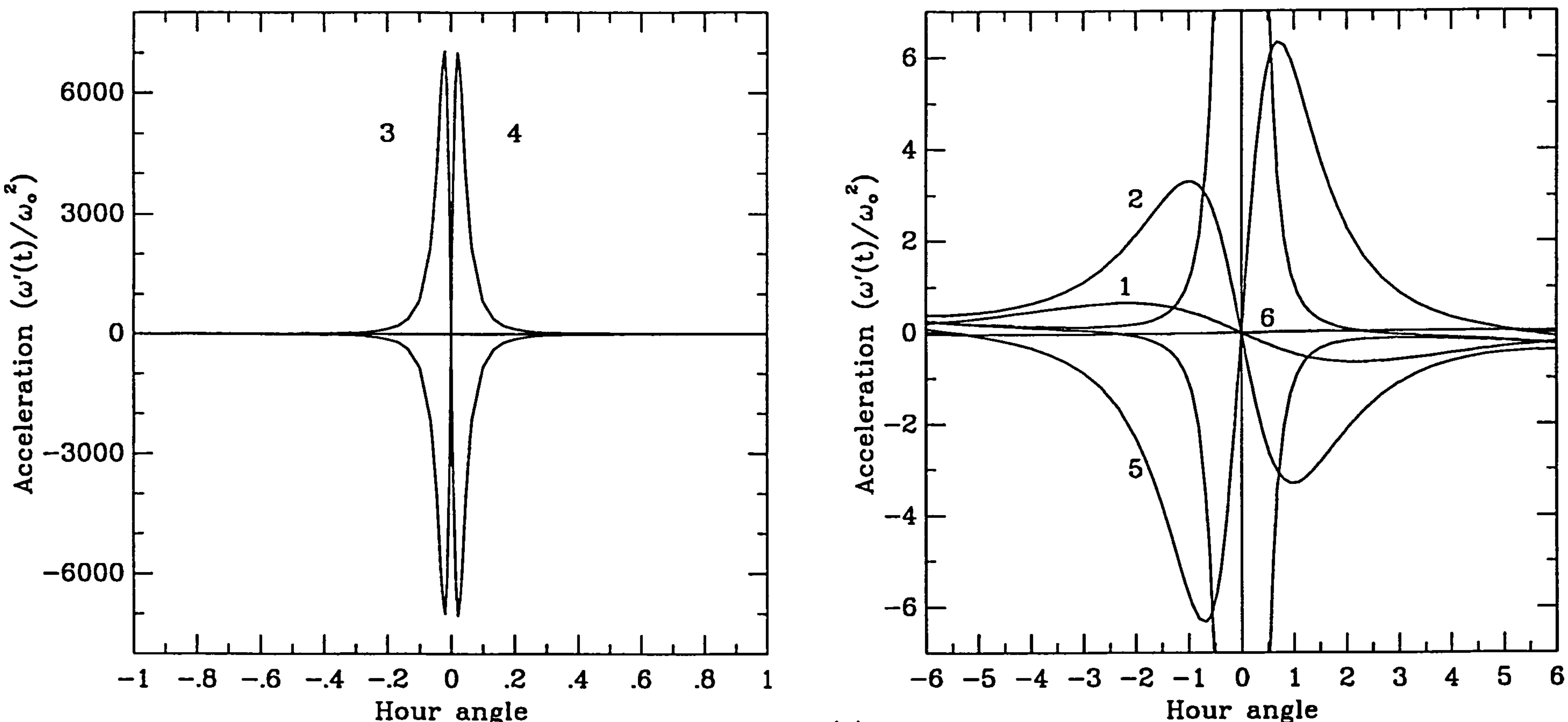
1	30°	4	−25°
2	0°	5	−40°
3	−24°	6	−85°

Figure 3. Field rotation at the Cassegrain Focus

a) Rotation.

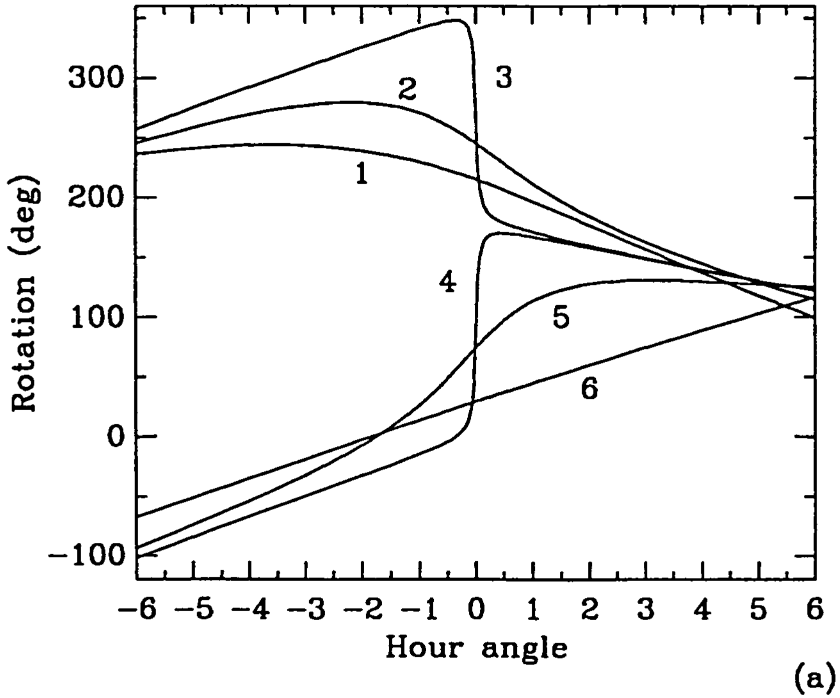
b) Velocity. $\omega_o = 15\ arcsec/s$.

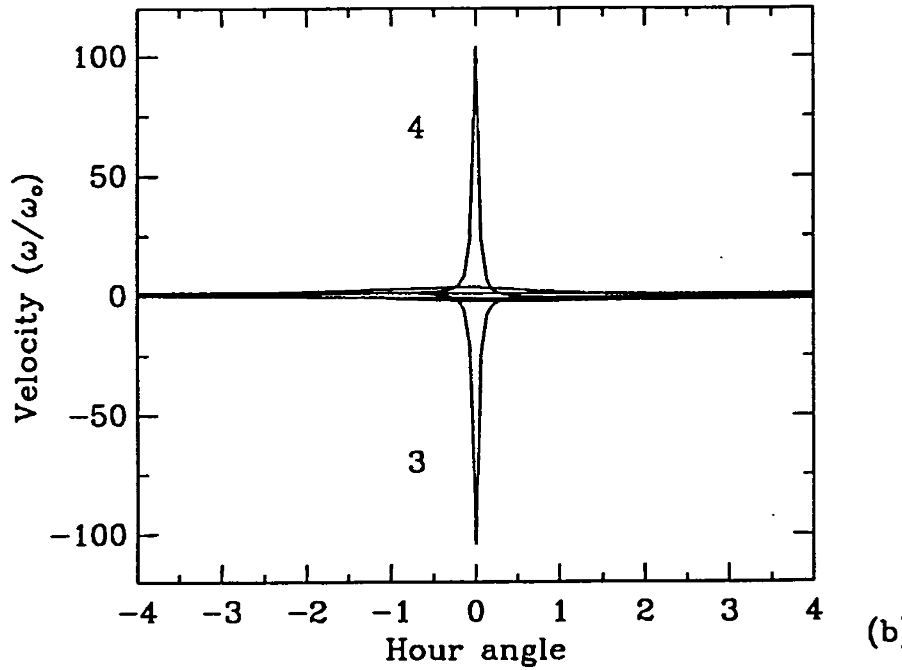
c) Acceleration. $\omega_o^2 = 1.091 \times 10^{-3}\ arcsec/s^2$.

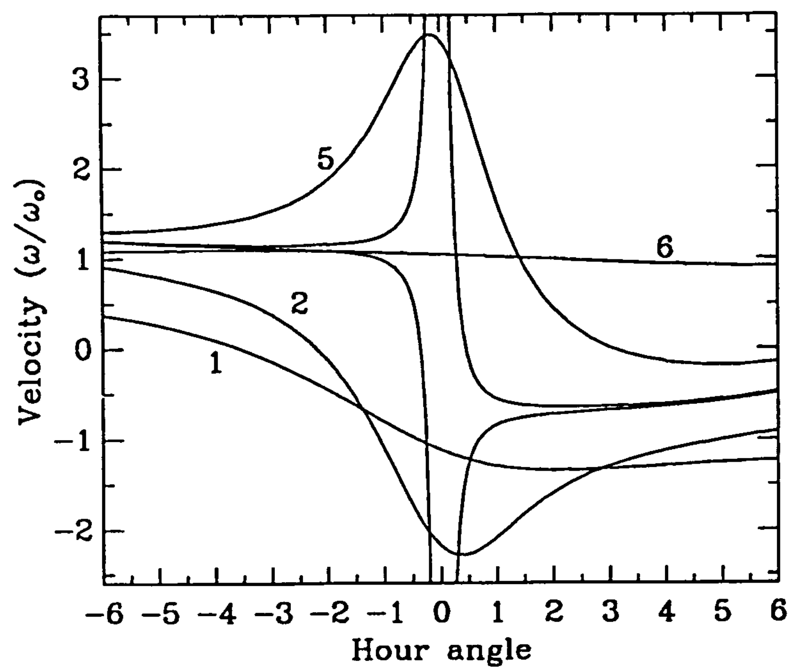


Acceleration $(\omega'(t)/\omega_o^2)$
6000
3000
0
−3000
−6000
3
4
−1
−.8
−.6
−.4
−.2
0
.2
.4
.6
.8
1
Hour angle
Acceleration $(\omega'(t)/\omega_o^2)$
6
4
2
0
−2
−4
−6
1
2
5
6
−6
−5
−4
−3
−2
−1
0
1
2
3
4
5
6
Hour angle

(c)

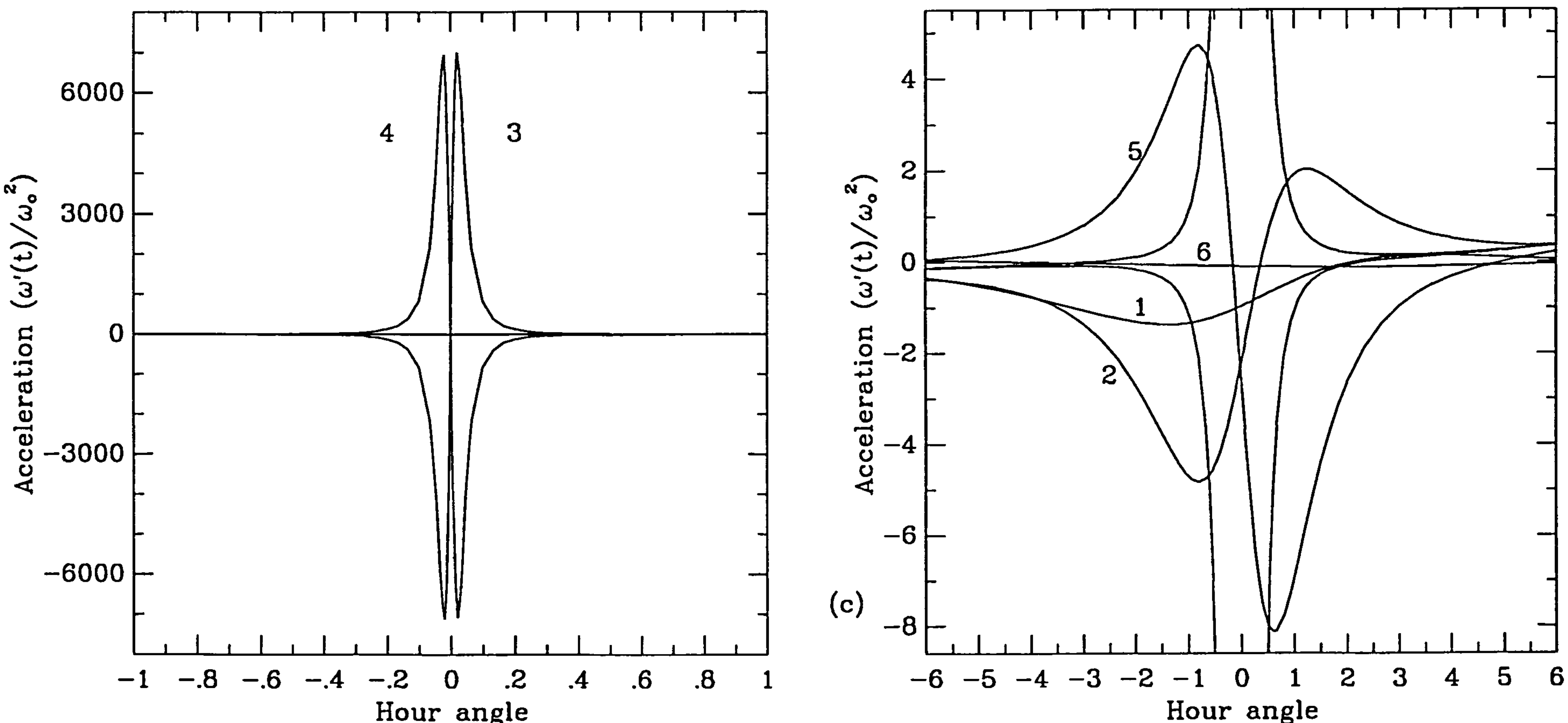






1	30°	4	−25°
2	0°	5	−40°
3	−24°	6	−85°

Figure 4. Field rotation at the Nasmyth Focus on platform B.
a) Rotation.
b) Velocity. $\omega_o = 15\ arcsec/s$.
c)Acceleration. $\omega_o^2 = 1.091 \times 10^{-3}\ arcsec/s^2$.



6000
3000
0
−3000
−6000
Acceleration $(\omega'(t)/\omega_o^2)$
4
3
−1
−.8
−.6
−.4
−.2
0
.2
.4
.6
.8
1
Hour angle
4
2
0
−2
−4
−6
−8
5
6
1
2
(c)
−6
−5
−4
−3
−2
−1
0
1
2
3
4
5
6
Hour angle

(c)

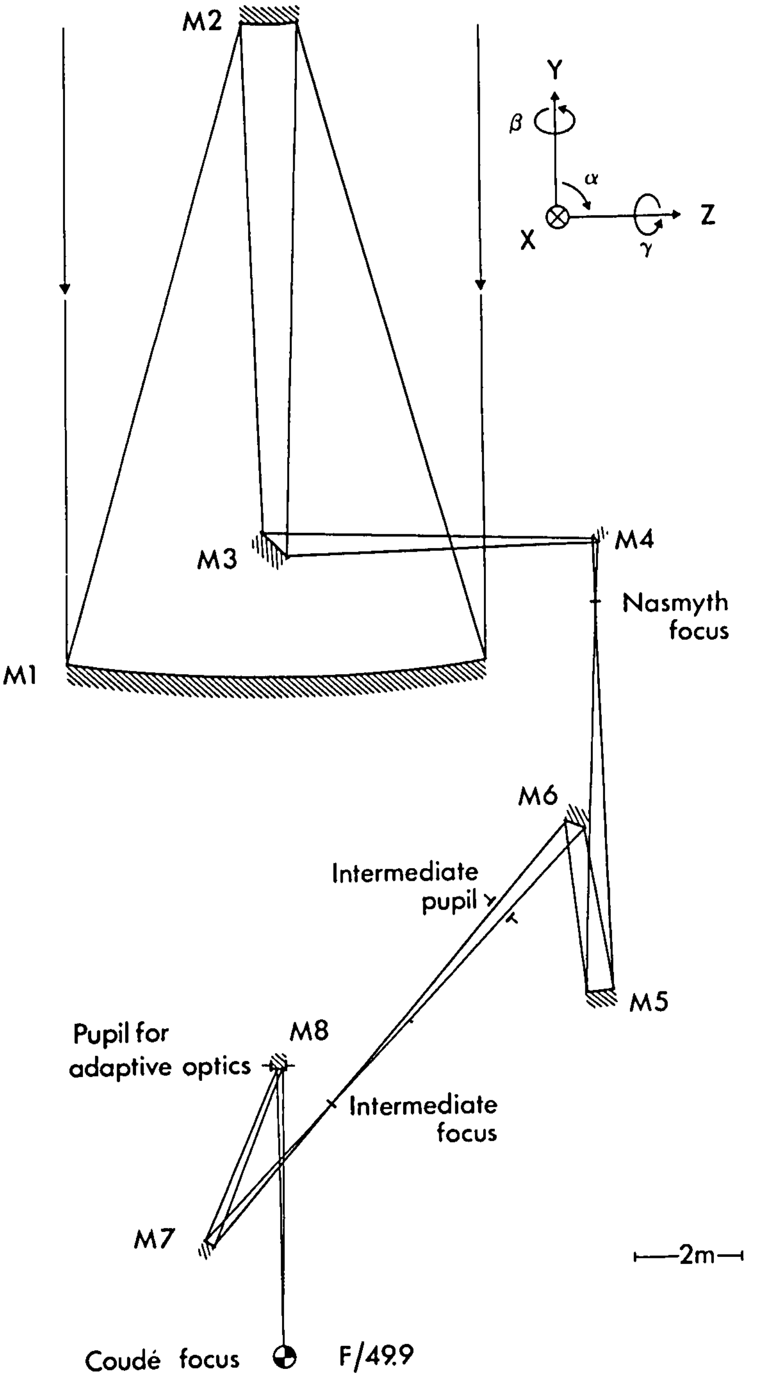
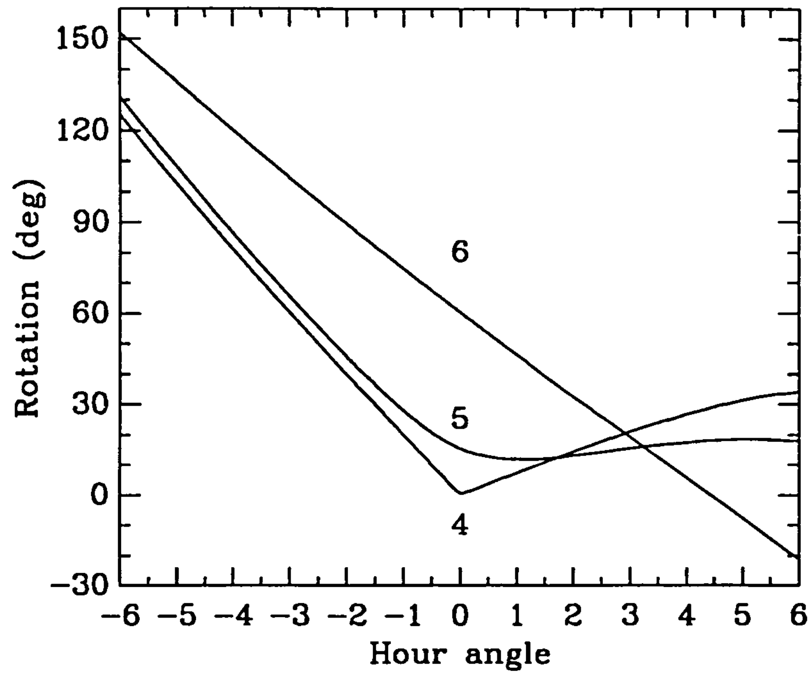
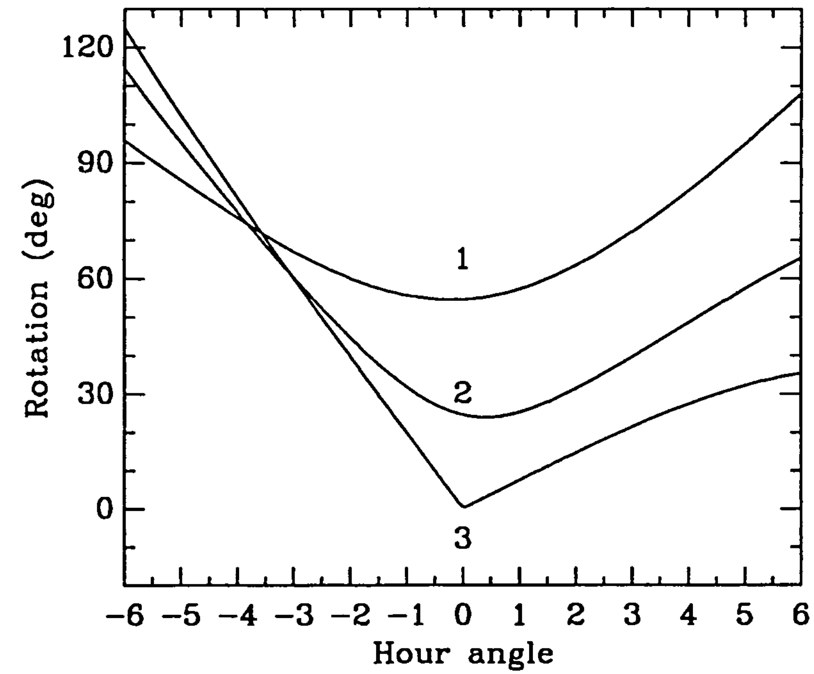


Figure 5. Optical Coudé Beam setup

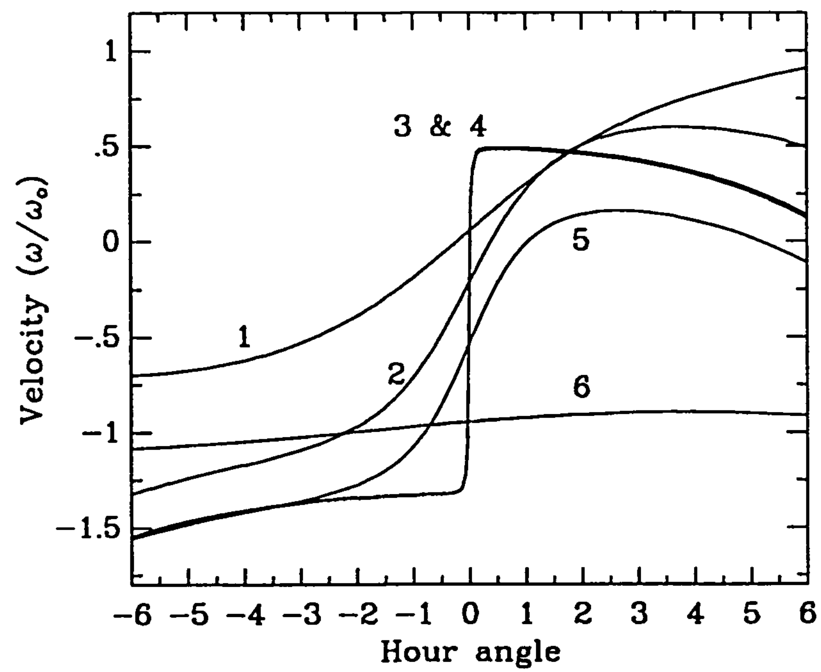




(a)

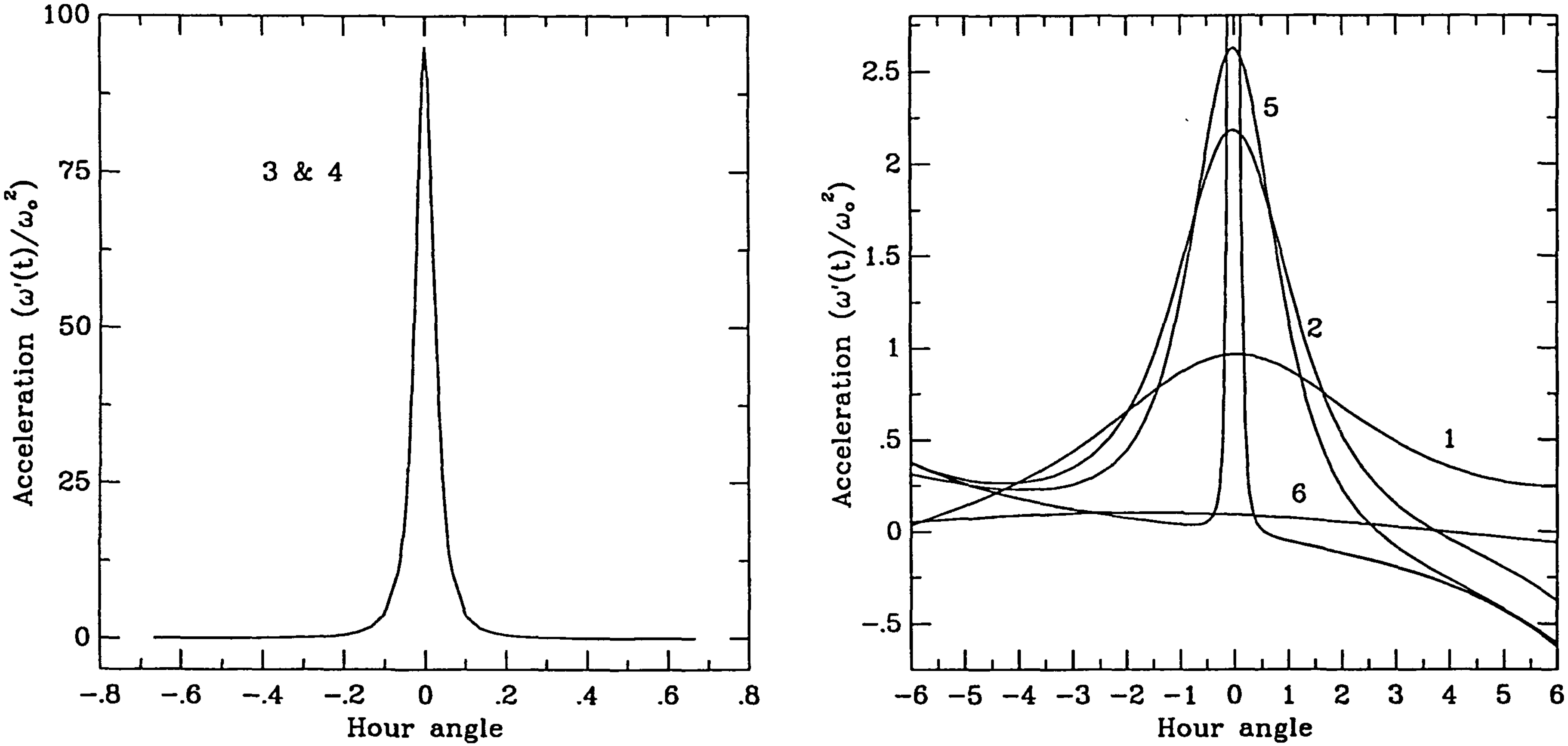
(a)

1	30°	4	−25°
2	0°	5	−40°
3	−24°	6	−85°



(b)

Figure 6. Field rotation at the Coudé or Combined Focus by way of B Nasmyth focus.
a) Rotation.
b) Velocity. $\omega_o = 15\ arcsec/s$.
c) Acceleration. $\omega_o^2 = 1.091 \times 10^{-3}\ arcsec/s^2$.


3 & 4
Acceleration (ω'(t)/ω₀²)
Hour angle
5
2
1
6
Acceleration (ω'(t)/ω₀²)
Hour angle

(c)

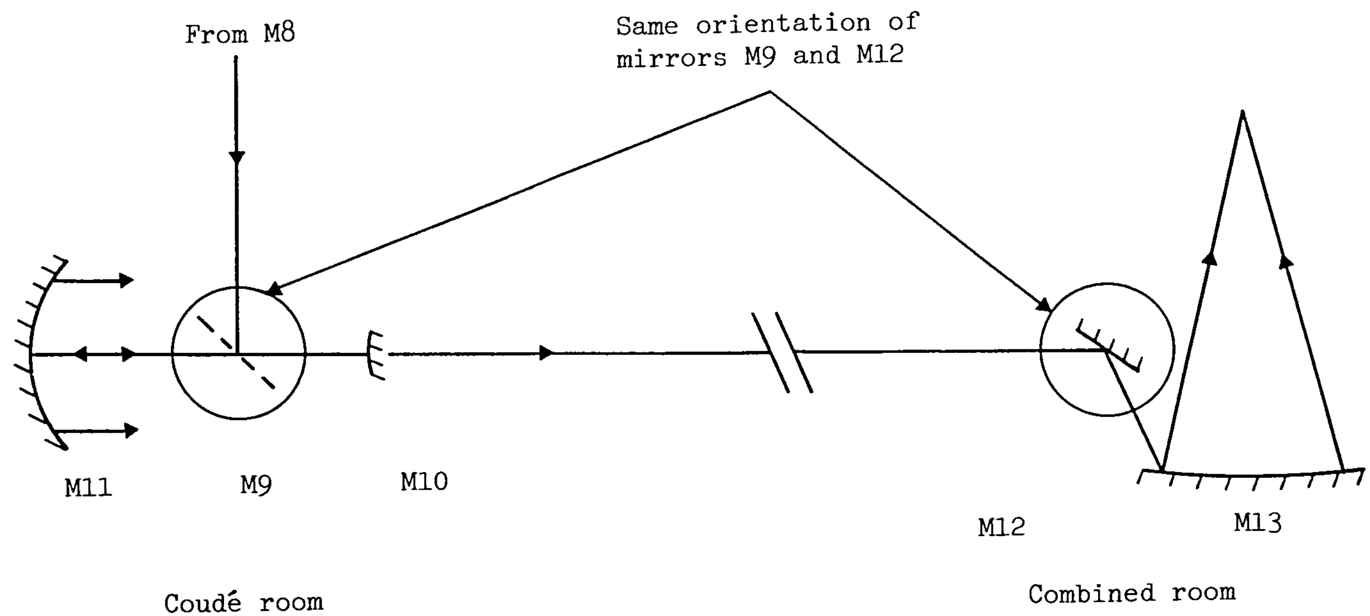


Figure 7. Mirror train for the Combined Focus

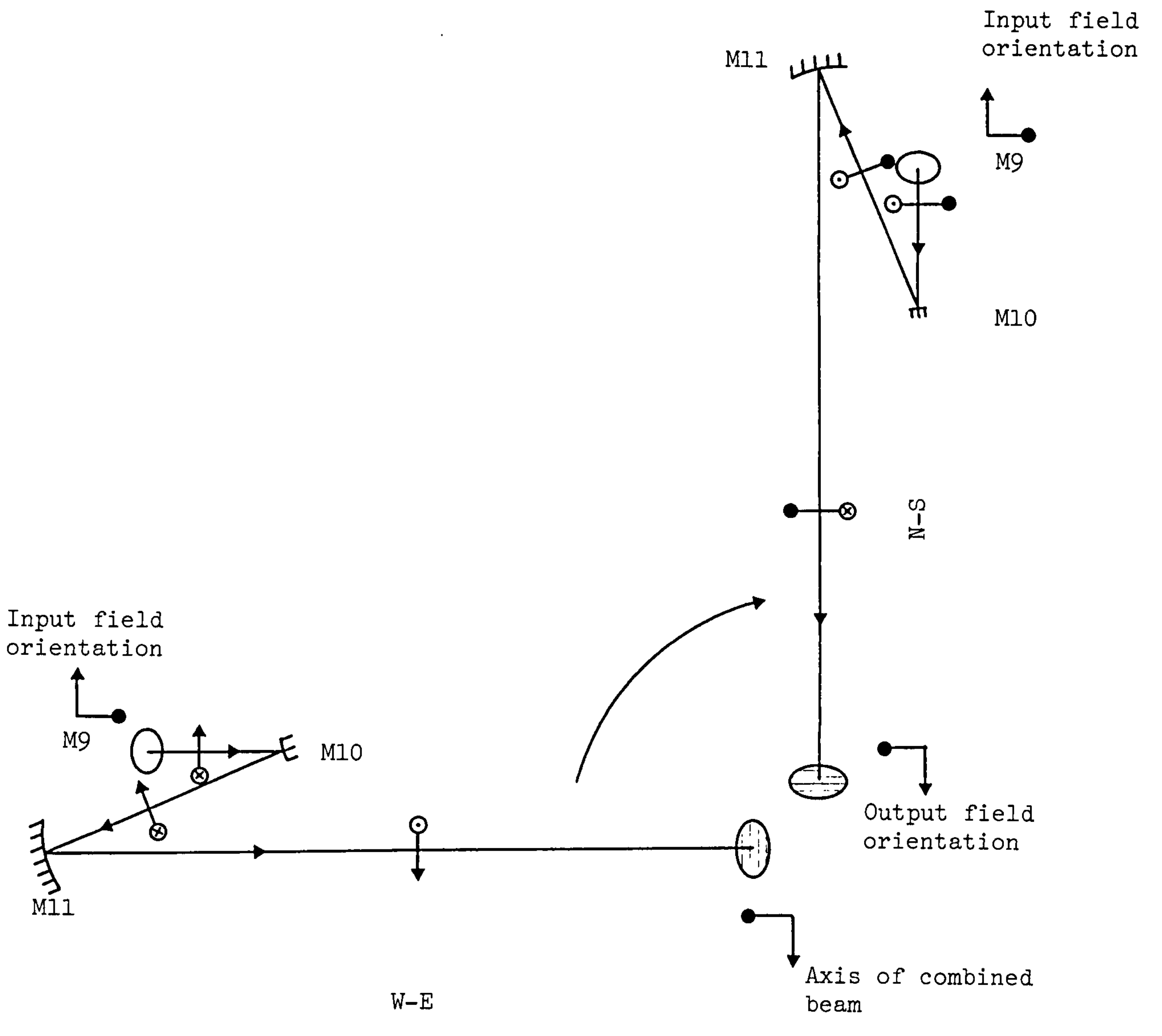


Figure 8: Field Orientation for any Telescope Array

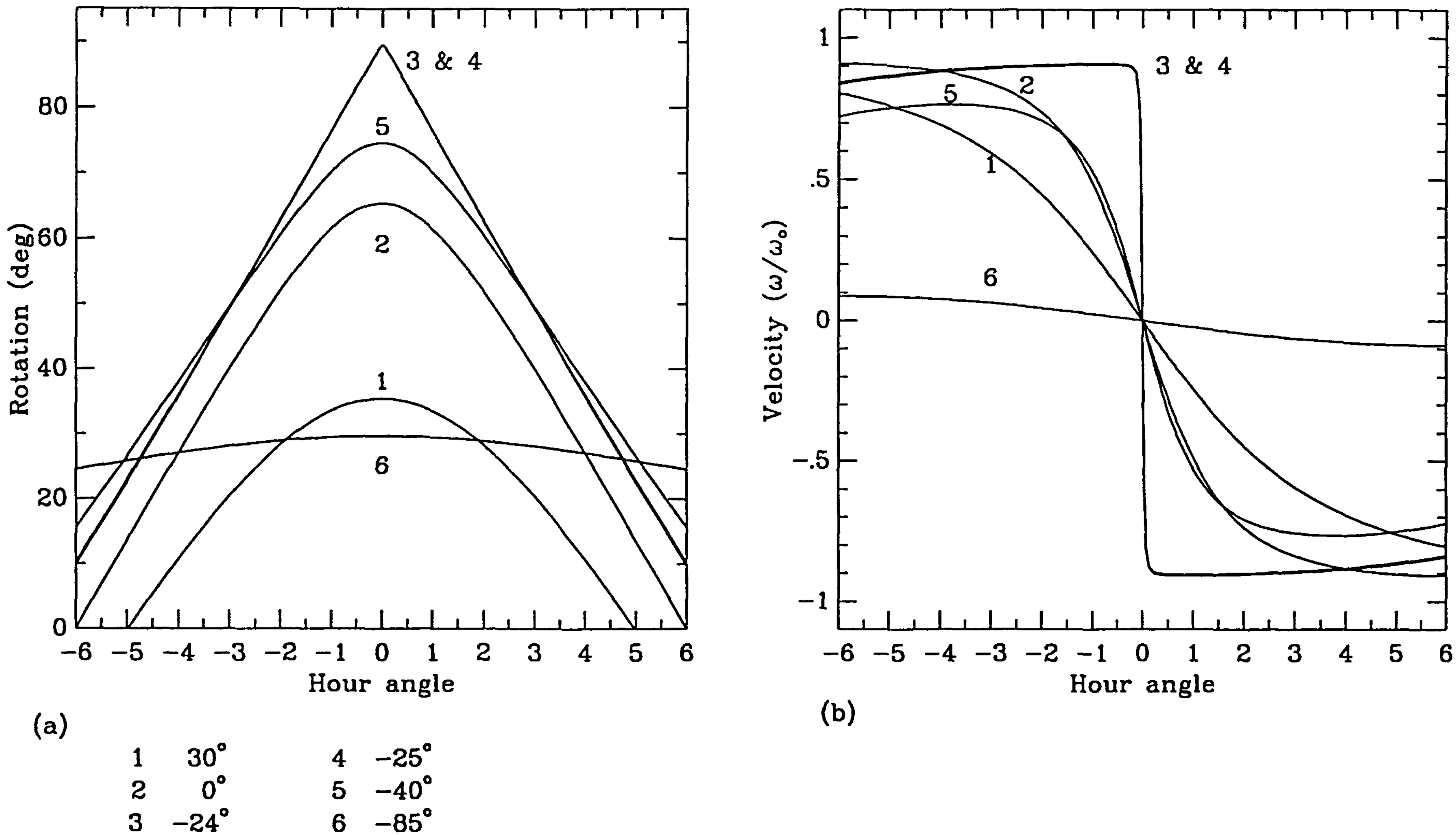
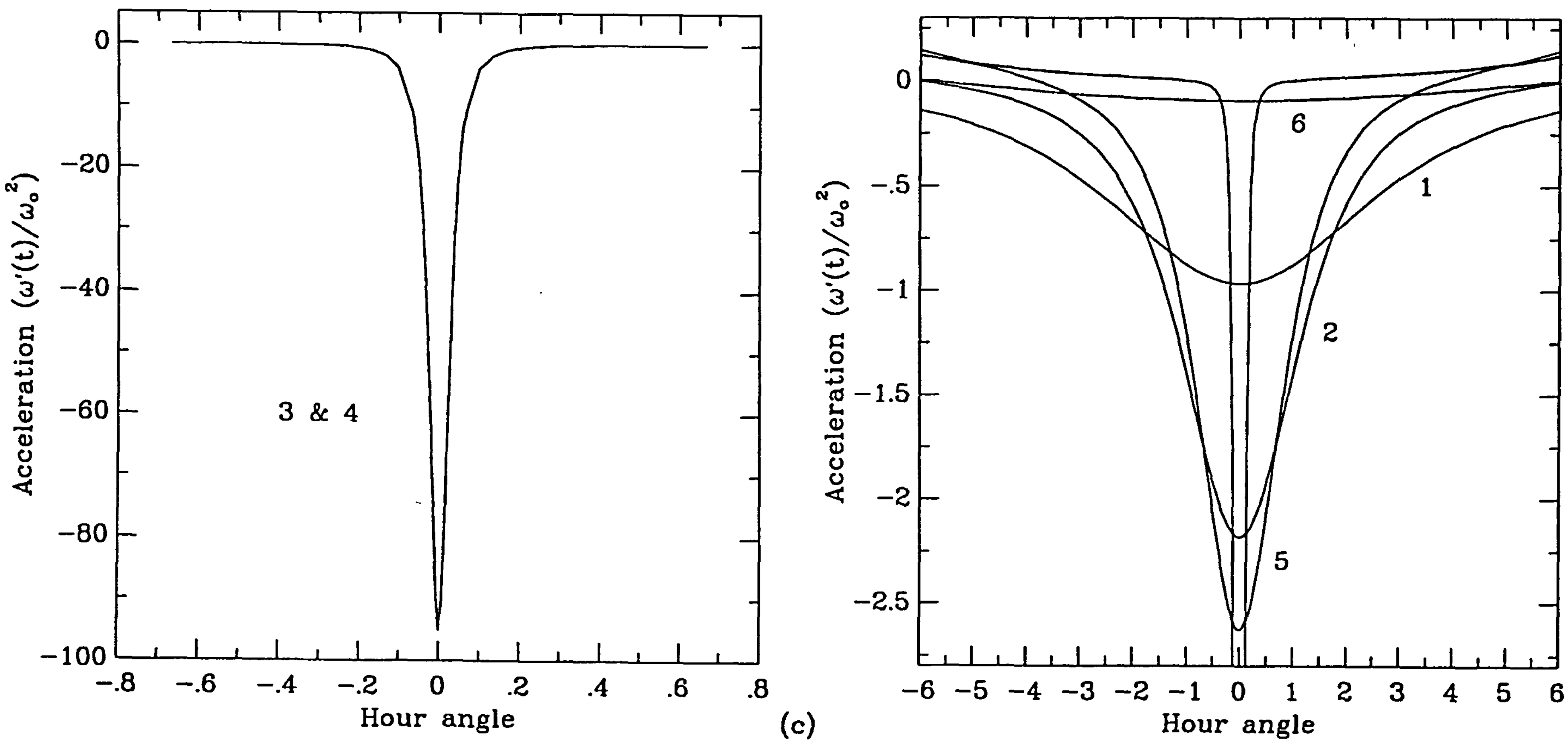
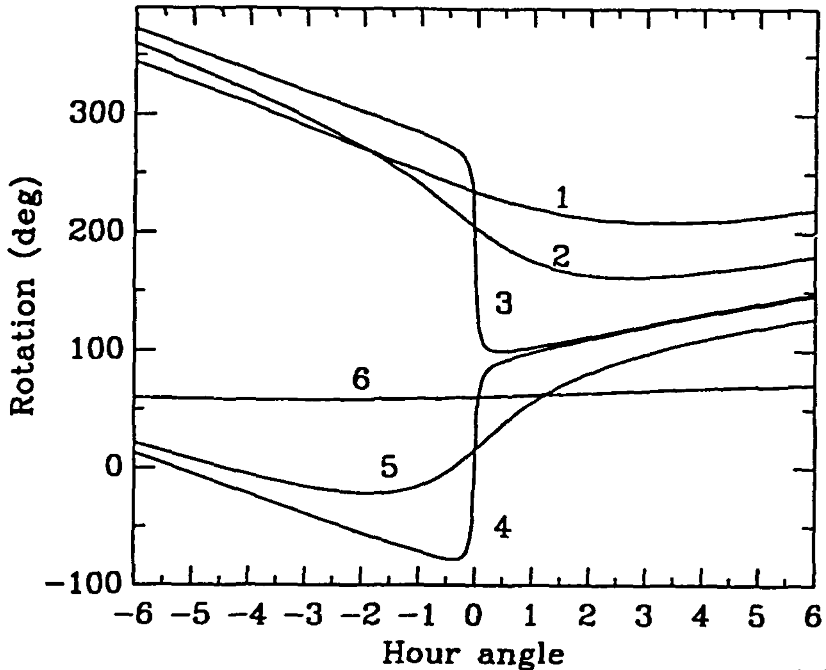


Figure 9. Pupil Rotation at the Nasmyth B platform.

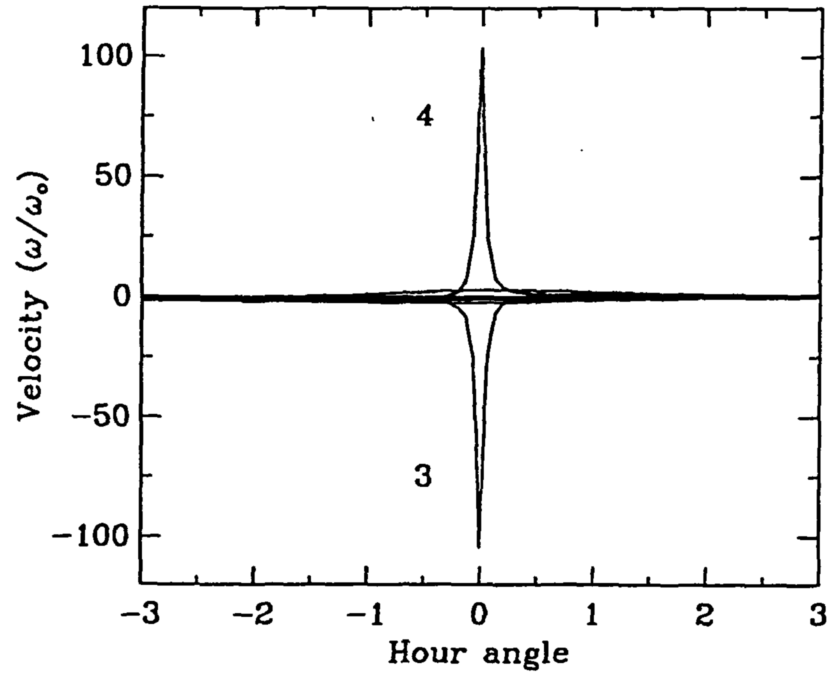
a) Rotation, (b) Velocity ($\omega_o = 15$ $arcsec/s$) and c) Acceleration.
$\omega_o^2 = 1.091 \times 10^{-3}$ $arcsec/s^2$.


Acceleration $(\omega'(t)/\omega_o^2)$
0
−20
−40
−60
−80
−100
3 & 4
−.8 −.6 −.4 −.2 0 .2 .4 .6 .8
Hour angle
Acceleration $(\omega'(t)/\omega_o^2)$
0
−.5
−1
−1.5
−2
−2.5
6
1
2
5
−6 −5 −4 −3 −2 −1 0 1 2 3 4 5 6
Hour angle

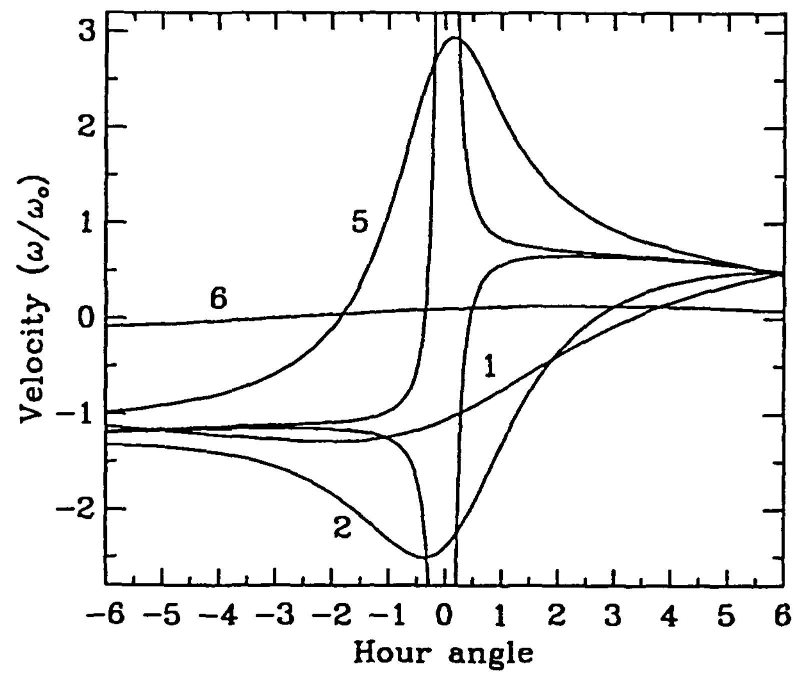
(c)



(a)

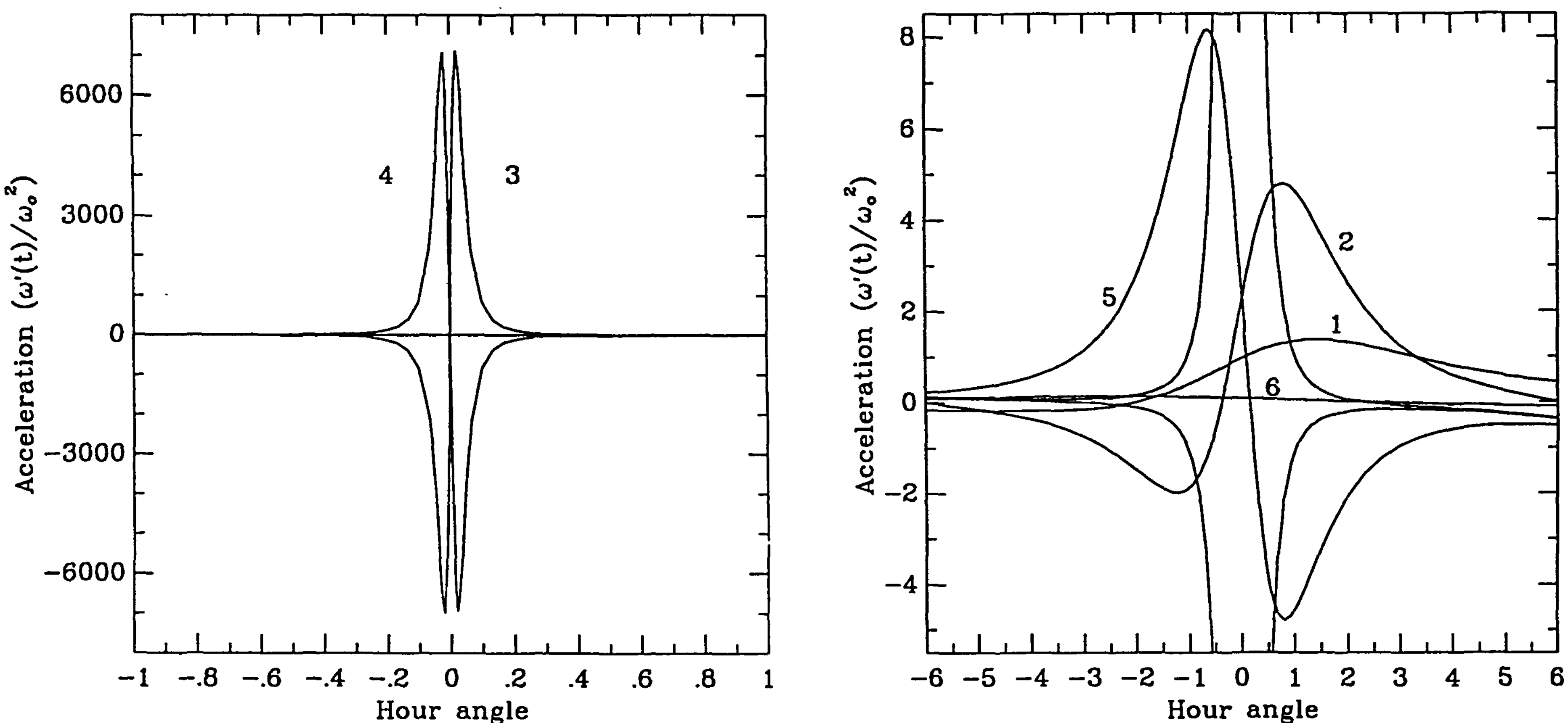


(b)



1	30°	4	−25°
2	0°	5	−40°
3	−24°	6	−85°

Figure 10. Pupil Rotation at the Coudé or Combined Focus by way of the Nasmyth B focus.
a) Rotation.
(b) Velocity. $\omega_o = 15\ arcsec/s$.
c) Acceleration. $\omega_o^2 = 1.091 \times 10^{-3}\ arcsec/s^2$.


6000
3000
0
−3000
−6000
Acceleration (ω'(t)/ω_o^2)
4
3
−1 −.8 −.6 −.4 −.2 0 .2 .4 .6 .8 1
Hour angle
8
6
4
2
0
−2
−4
Acceleration (ω'(t)/ω_o^2)
5
2
1
6
−6 −5 −4 −3 −2 −1 0 1 2 3 4 5 6
Hour angle

(c)